Vol. XVII, No. 3 July 1, 1946

University of Arizona
Bulletin

LABORATORY OF TREE-RING RESEARCH
BULLETIN NO. 3

PRECISION OF RING DATING IN TREE-RING CHRONOLOGIES

By A. E. Douglass

Published By
University of Arizona
Tucson, Arizona

University of Arizona Bulletin

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STATEMENT OF MAILING PRIVILEGE

The *University of Arizona Bulletin* is issued quarterly.

Entered as second-class mail matter December 29, 1936, at the post office at Tucson, Arizona, under the Act of August 24, 1912. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized June 29, 1921.

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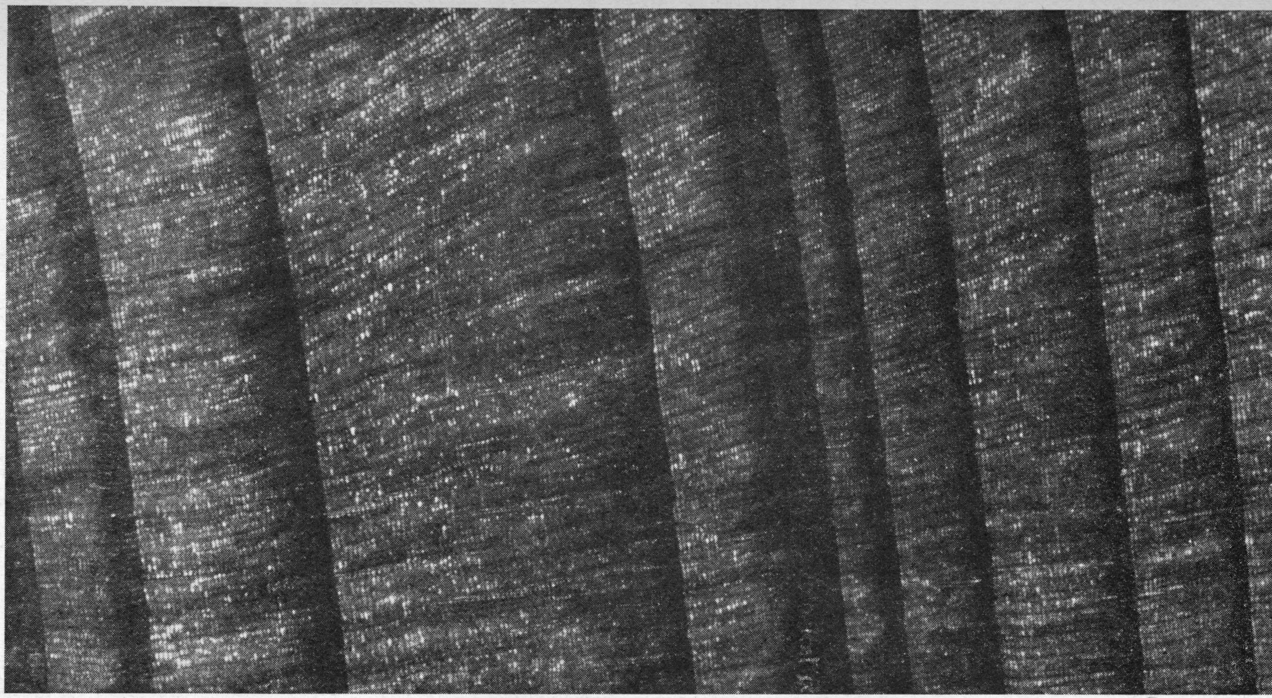
ILLUSTRATONS



Frontispiece (Pl. I).—Cell illumination to emphasize the annual rings in wood. Specimen BK120, enlarged X 24; photo at Laboratory of Tree-Ring Research by H. Faurest Davis. Ring dates are 1182 to 1189 and part of 1190 (left to right).

The purpose of this paper is to emphasize the precision of the dating of individual rings in long tree-ring chronologies by the use of methods and procedures classed under the name "dendrochronology." These operations are based on climatic impressions upon the individual rings of trees—trees so located that climatic changes from year to year are of highest importance to the individual tree. The climatic source of these impressions is identified by the faithful agreement between many trees, in the resulting ring patterns year by year, through the active lives of contemporary trees as will be shown below; thence this tree-ring chronology is extended back nearly 2,000 years in the Southwest by the overlapping lives of generations of trees.

Archaeological dating, whose results have been more generally published, sometimes follows this precision dating very closely. But in most cases, one, two, or three corrections are needed, usually very small but rarely strictly precise: (a) for crowded and unreadable outside rings; (b) for definite loss of outside rings; and (c) for lapse of time from death of the tree to its actual use in house construction or for other purpose. The actual extension of this dating back through the centuries has depended strongly on the archaeologists who generously supplied the specimens. So the name dendrochronology has been associated with their work.

THREE ESSENTIALS IN ATTAINING PRECISION

In securing precision in the dating of tree rings there are three essentials which must be carefully observed, namely: (a) site classification of trees to get the right trees; (b) proper surfacing of specimens to get the facts about the individual rings; and (c) crossdating, or the comparison between ring groups in different trees, to correct ring errors and determine climatic effects.

FIRST ESSENTIAL: SITE CLASSIFICATION OF TREES

This was the last of the three to be understood by us, for its real appreciation can come only to the widely traveled and understanding fieldman. Its lack is the first general cause of failure in certain attempts to "test" tree-ring work and results.

Climate recording qualities require of forest trees a classification based on site in relation to moisture supply (in the Southwest) or to temperature (in Alaska) which control ring type. Thus in the dry Southwest the tree in a valley bottom or near a constant source of water makes an entirely different ring record from a tree on a high isolated point or growing in a crack in a rock or thoroughly protected from any "imported" water and obviously limited by nature to dependence on the precipitation immediately about it; under the stress of deficient moisture its rings may tell a special story of its water supply year by

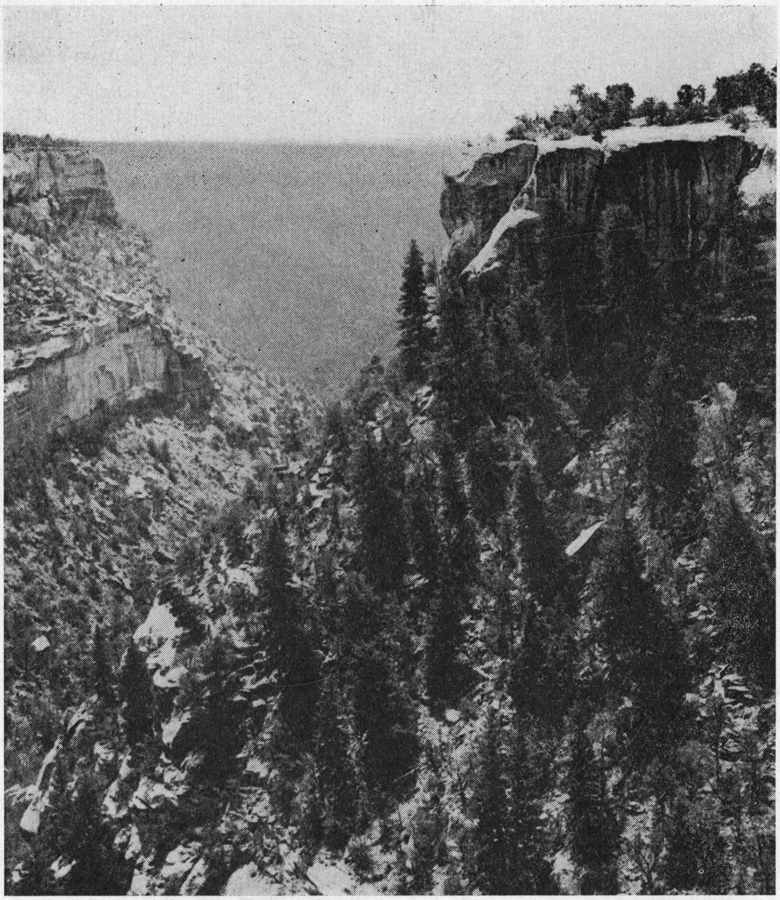


Plate II.—Type site of trees giving climatic ring records. Fewkes' Canyon, Mesa Verde National Park. These trees on the steep slope depend on precipitation close about them.

year (Pl. II). This idea is common and sensible to the people who have lived long in this basically dry country, but those living in the eastern seaboard find it hard to believe. Even on the western seacoast trained people can fail to notice the effect on tree-ring growth of an insistent dryness.

A specific example may be cited. In a group of twenty-one increment cores a student discarded the only good ones (which were sensitive but which he thought were merely erratic) and measured worthless specimens because he did not understand the different ring types resulting from different sites.[1] In long experience we have learned to judge the original growth site of specimens by the quality and excellence of their crossdating. (See third essential below.)

Our realization of the importance of local site in tree-ring records came extensively in work on sequoia ring records between 1915 and 1927.[2] That beginning of the understanding of site was followed up in the more sensitive trees in the dry areas of Arizona and the Pueblo area, as will be told later, and led eventually to a "type site" in Mesa Verde National Park.[3]

Our preferred trees in this Southwest are Ponderosa pine and Douglas fir. The differences in climatic chronology between these two are very slight indeed if many trees of high quality are used to represent each species. There are some differences in individual trees as to intensity and consistency of reaction. Schulman has shown that the Douglas fir in its best sites is most satisfactory, and we are using it as a standard. In his extensive collecting he has found superb sites in widely separated areas.[4]

Application of first essential.—In hydrological studies which use modern trees, the site as here described is the first consideration; this is because the principles of tree-ring growth in relation to site guide us to the place where the proper trees are found. Increment borings in the trees, examined if possible on the spot, then show whether crossdating exists or is likely to exist in these trees, and further borings are made accordingly. In case of archaeological specimens only a rough approximation can be made of the site and often none at all is possible. So archaeological specimens are judged directly by the existence and accuracy of the crossdating, and those of highest quality in this respect are studied first.

SECOND ESSENTIAL: SPECIMEN SURFACES AND RING READING

In the effort to attain precision in dating, proper surfaces are of the highest importance because the correct identification of rings depends on them. The composition and function of an annual ring and therefore its recognition rest in the microscopic cell structure, shape, and color which can only be seen with certainty on a practically perfect surface good enough for microscope powers of X 60 to X 200, and the use of daylight for color.

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[1] "Crossdating in Dendrochronology," *Journal of Forestry*, Vol. 39, No. 10, October, 1941, pp. 825-31.

[2] *Tree-Ring Bulletin*, Vol. 12, No. 2, October, 1945.

[3] Plate IV, "Climatic Cycles and Tree Growth," *Carn. Inst. Wash.*, Publ. 289, Vol. III, 1936, and Plate II, this Bulletin; also "The Mesa Verde Type Site," *Tree-Ring Bulletin*, Vol. 6, No. 2, October, 1939, p. 11.

[4] "Tree-Ring Hydrology of the Colorado River Basin," *University of Arizona Bulletin*, Vol. 16, No. 4, 1945.

Specimen surfaces

Coniferous wood surfaces.—In 1906 to 1911 during work on the large Flagstaff pine sections a surface cut with a heavy razor and sometimes with a knife was very hard on razor or knife blades, thus leading constantly to neglect of complete surfacing. Filing a surface with a round file was unreliable in difficult cases; therefore we do not now trust abrasives.

Beginning in 1911 with the introduction of "V-cuts" it was easier to cut on their slant sides that showed a smaller angle to the grain, which gave more readable surfaces. Especially fine views of the rings were obtained by letting the light from the window or lamp come to the specimen's diagonal side over one's shoulder. This improvement which is still in use was seen to come from some relation of the light beam to the direction of the cells of the woods. That led to the diagonal cut and the use of light reflected from the cell walls to brighten the earlywood parts of a ring in contrast to the dark latewood (Frontispiece, Pl. I).[5]

This diagonal, cut 35° to 40° from the grain with properly directed illumination, is essentially a microtome cut, to be examined by reflected instead of transmitted light, and is the best type of surface on wood for judgment upon the annual or nonannual character of a doubtful ring. It is an especially favorable way to be certain of satisfactory illumination for the photography of wood specimens.

Charcoal surfaces.—For low magnifying powers X 5 or X 10 in this study of the rings in charcoal there is no surface superior to the natural cleavage if it is reasonably fresh. It practically sparkles in its brilliance and precision and any power in the microscope can be used on it over large areas if the continuous cleavage surface is large. But frequently it is not large or is so badly shaped that surface fragments have to be chipped off to make the rings visible. Though the resulting surface is far from flat, it is still highly efficient in reaching a decision on doubtful rings for visual work. (See Pl. V *A*.) Such surfaces can be photographed at low enlargement with small lens aperture to give good definition; then the negative can be enlarged.

A different procedure may be used if the charcoal pieces have been dipped in some slightly binding solution such as a weak solution of paraffin in gasoline, which prevents the charcoal from falling to pieces if it waits too long for laboratory study. Then one is able to cut the needed flat surface with only a partial decrease in brilliance of rings. Frederick H. Scantling, working in our laboratory, has obtained very fine results with a certain baking which he gives the paraffined speci-

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[5]"Techniques of Tree-Ring Analysis," *Tree-Ring Bulletin*, Vol. 7, No. 4, April, 1941, pp. 28-34.

mens before cutting the surface. His report on the method, a modified form of one described by E. T. Hall, has been recently described.[6]

Dangerous practices.—Any process of using an abrasive blast on very fragile charcoal should be utterly abandoned. It makes hardness the criterion of ring identity instead of cell structure, shape, and color, and is wholly untrustworthy. A careful examination of a considerable number of such surfaced specimens, perhaps 150, showed not a single case in which a trustworthy ring reading could be obtained. It was necessary to chip a new surface on every specimen.[7] This error should have been publicized and eliminated long ago by presenting full photographs of the original ring surfaces from which the readings were plotted, a policy suggested in early Tree-Ring Society meetings.[8]

Another deplorable policy in the handling of charcoal specimens should be abandoned. It is a waste of valuable material by cutting the charcoal fragments to a conventionalized form of thin slab, such as 1/2 to 1 inch thick. This involves loss of its archaeological connotation, as well as loss of parts that might be sent to other laboratories; but more important is the loss of added display of the individual rings by which a better judgment of their climatic meaning is reached. A missing ring could have its only presence in the specimen cut off and lost by this practice. The possessor of a prehistoric specimen enjoys a trust and so has an obligation to other students to give such specimens the best special care.

Some reasons for errors.—Dating work is largely a numerical placing of deficient rings. That means a memory for numbers because placing individual rings in a series of consecutive dates is the easiest certain and the quickest way of identifying the rings. To many people this numerical phase is very hard work, and they are greatly relieved when they turn to tangible plots. To them the plot is real and the chronology on the specimen is not, and to put much time on the transition is a hardship whose importance they overlook. (See Pl. VII *D* and its plot Fig. 1.)

Then again there has been a feeling that statistics relieve the student of responsibility. That can only be true if the basic data are homogeneous. They are considered to be homogeneous if the quantitative distribution of errors makes the right curve (normal distribu-

[6]Hall: *Tree-Ring Bulletin*, Vol. 5, No. 4, April, 1939, p. 31, and Vol. 12, No. 4, April, 1946, p. 26.
Scantling: *ibid.,* p. 27. See also Pl. IV.

[7]These charcoal surfaces, impossible to read, and wood surfaces produced by an abrasive, combined with the absence of the precision check of crossdating, make untrustworthy all dating results so obtained. See, among others, Gila Pueblo *Medallion Paper XXVII*, p. 7. On the other hand our own dating techniques require complete crossdating and dating before measurement so that dated rings can be averaged together, a sufficiently obvious advantage.

[8]"Accuracy of Dating," *Tree-Ring Bulletin*, Vol. 1, No. 3, Jan., 1935, p. 20.

tion). But trees and their ring records are not homogeneous. Some are good recorders of climate and some are very bad ones.

Perhaps a background for errors is that need for exhausting thoroughness. That has meant dissecting logs to see if somewhere a prodigal ring returns. All these mean delayed decisions and that is abhorrent to certain temperaments. These operations cannot be done by an untrained person. The new student would save much time in his real understanding if he could spend some months doing intense work in our laboratory which is partially designed for teaching.

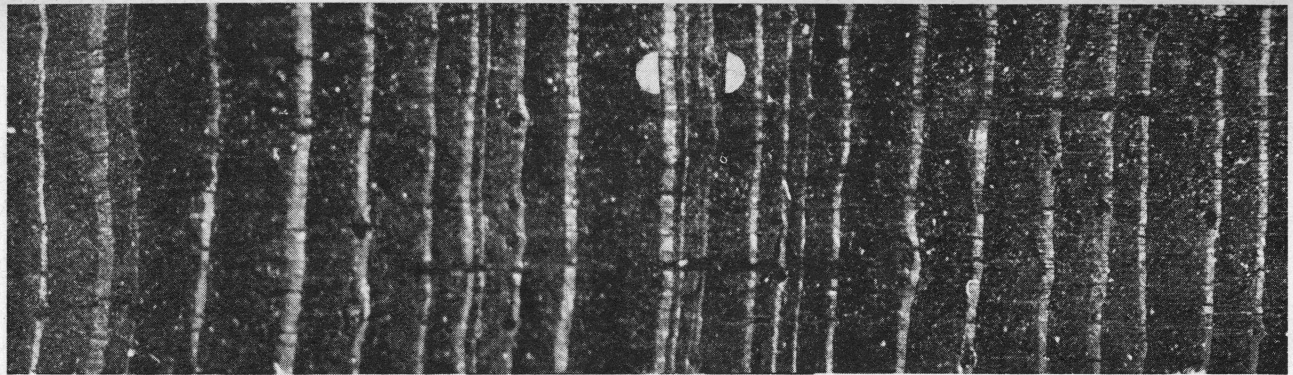
Ring reading

Good surfaces lead directly to prompt and correct reading or enumeration of the rings so necessary in precision dating. However, the unaided student meets certain difficulties.

Double rings.—A wide earlywood (spring growth) with a faint latewood (summer or autumn growth) followed by a narrow earlywood with a heavy latewood makes the common form of a double ring in our southwestern areas, especially in pine. Such a combination is likely to be a double ring. To settle its character the earlier of the two latewoods is first enlarged to see if its latewood character fails (Pl. III); failing a decision, it is then followed about the circuit and if it stops or fades into a hazy form in the circuit, or if anywhere it is joined to the other latewood by hazy extensions or heavy-walled cells or by a color that suggests heartwood, then it is part of a double. However, if the two latewoods obviously merge together, then they are presumably two annual rings. Any decision reached this way by examination of one tree-ring record is then subjected to comparisons with the same dated rings in other trees. In the vast majority of cases this nonannual latewood is weaker and fainter than the true annual latewood and usually is distinguished by a hazy outside.

Micro rings.—Exceedingly small rings, often called micro rings, including those just outside a large latewood ring, are of first importance in crossdating. Their discovery in a place predicted beforehand gives some of our strongest dating. We list four tests which support or prove their definite reality as annual rings: (a) micro rings supply the real agreement between ring growth and rainfall; (b) in our constant experience they are merely one term in a series of diminishing ring width as an effect of less and less water supply; (c) they have to be taken as annuals in counting one ring to a year in checking the habit of trees; and (d) the structure of the micro rings as to the cells and their shape in earlywood and latewood shows them to be normal rings (Pl. IV).

Missing rings.—An assumed missing ring may be found in other parts of the specimen within an inch and yet sometimes is not found at all. It has a better chance in the vicinity of a knot where the rings have a reversed curve. Many difficult ones have been found in this



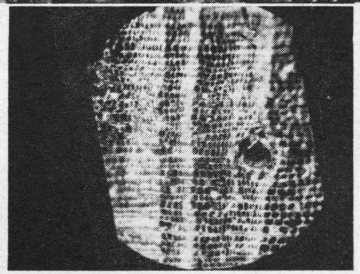


Plate III.—Study of double ring A.D. 631 in F. 3992, Baker Ruin, Flagstaff. (Our specimen received by courtesy of Museum of Northern Arizona.) *Above*, enlarged X 11; white semicircles enclose rings A.D. 630 and 631 with the possibility that 631 is two rings. *Below*, 630 and 631 enlarged X 33. The nonannual character of the first latewood of 631 is shown by its discontinuity and hazy outer edge.

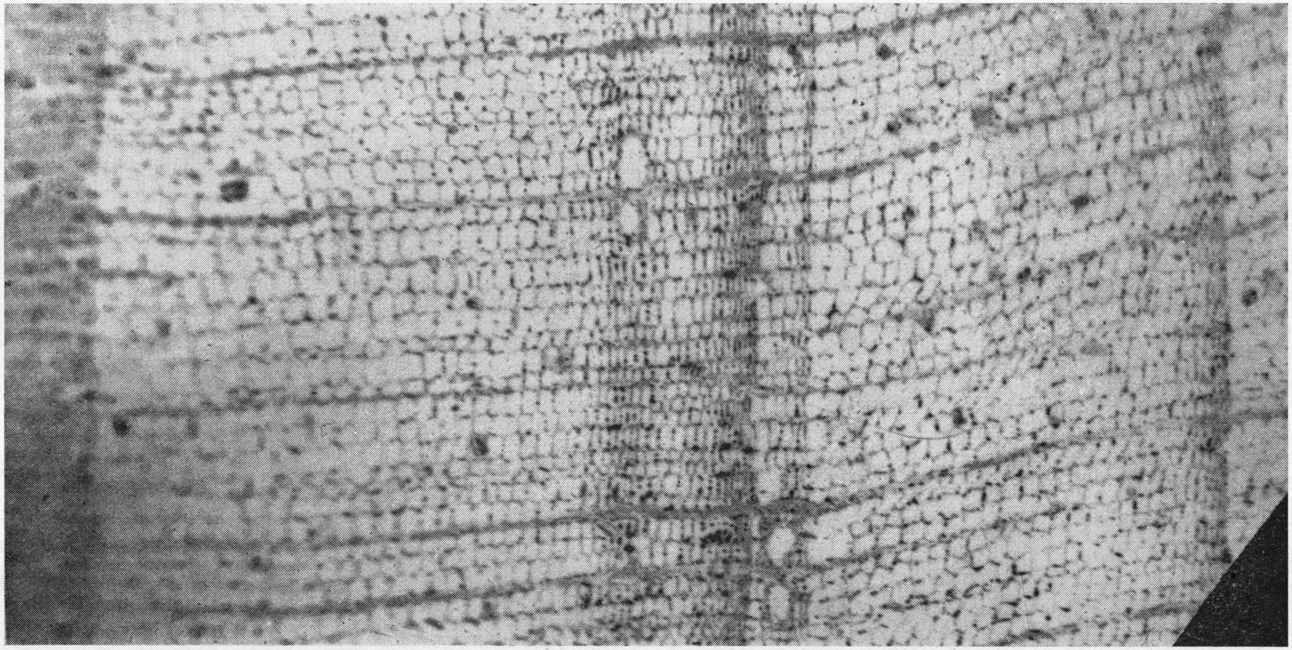


Plate IV.—Study of micro ring, A.D. 1067. Black Mesa specimen W-35/7. (Rainbow Bridge-Monument Valley Expedition, 1937.) Actual width of ring about 0.06 mm. Enlargement X 115 to show cell structure which, confirmed by crossdating, establishes the annual character of this micro ring. This photo negative from an opaque charcoal surface, prepared by Scantling, using a standard process.

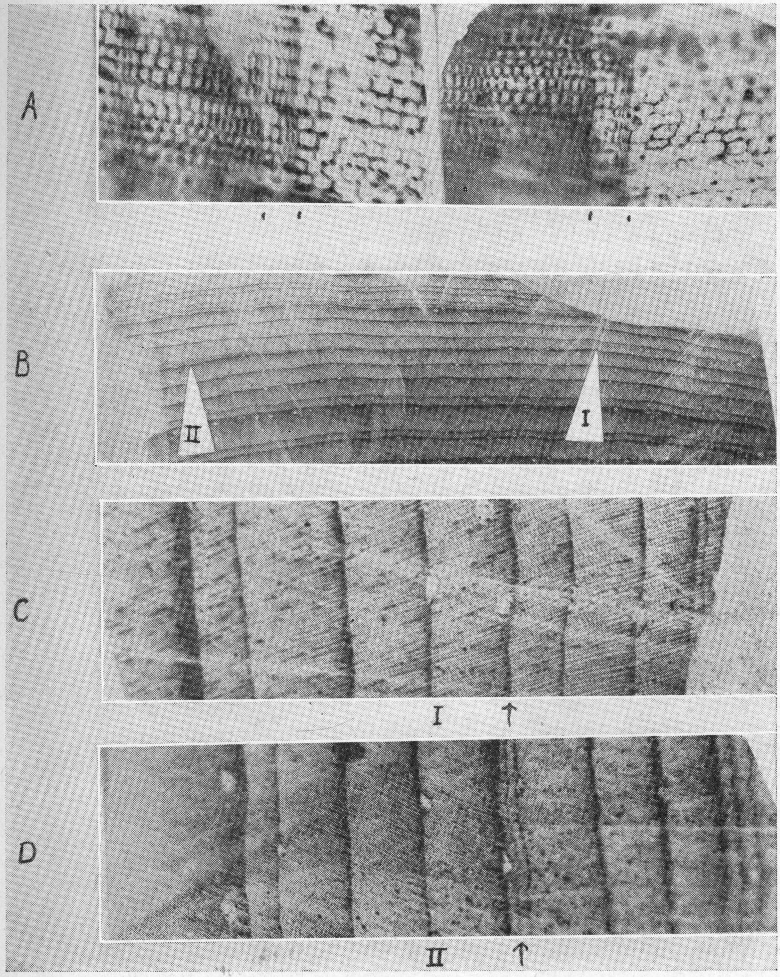


Plate V.—*A*, study of micro rings A.D. 611, *left*, 660, *right*, on specimen EWH's FST-18 (GP 3692 a) from Forestdale, Arizona. This charcoal specimen came to us surfaced by abrasion and these rings, about 0.06 mm. in thickness, were wholly invisible. A new surface was chipped in which they were easily seen and photographed as above. They were here presented as photo negatives enlarged X 75. *B*, *C*, *D*, study of verified prediction or "forecast" rings A.D. 257-58 in FST-200, pinewood, Forestdale. *B*, shows on small scale the complete rings; *C*, shows an enlargement of a part of the ring pattern in which the two absences were predicted (at location I); *D*, shows on the same scale the ring patterns in which the two "forecast" rings are present (at location II in *B*).

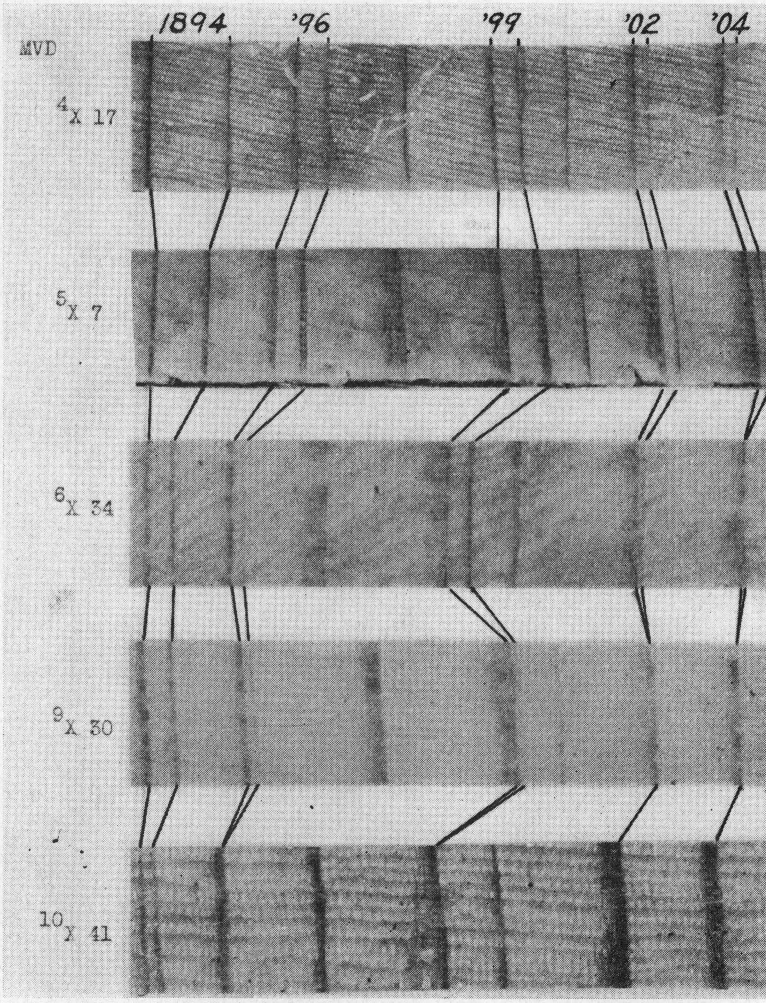


Plate VI.—Study of missing rings. Progressive absence with diminished water supply. Trees in Mesa Verde National Park. Numbers MVD 4 and 5 near Spruce Tree House; numbers *6*, *9*, and *10* in type site of Pl. II. (This cut reduces size to ¾ of enlargments marked at left.)

way, such as A.D. 907 in BE-67[9] and old JPB specimen in which years ago this favorable place for missing rings was first noticed, and

[9]BE-67, *Tree-Ring Bulletin*, "Techniques II," Vol. 7, No. 4, April, 1941, p. 30, Fig. 9 *A* and *B*. That ring was found fourteen years after it was located as missing. For reversed curvature near a knot see *Tree-Ring Bulletin*, Vol. 12, No. 4, April, 1946, p. 29, Fig. 1 *D*, showing ring A.D. 320.

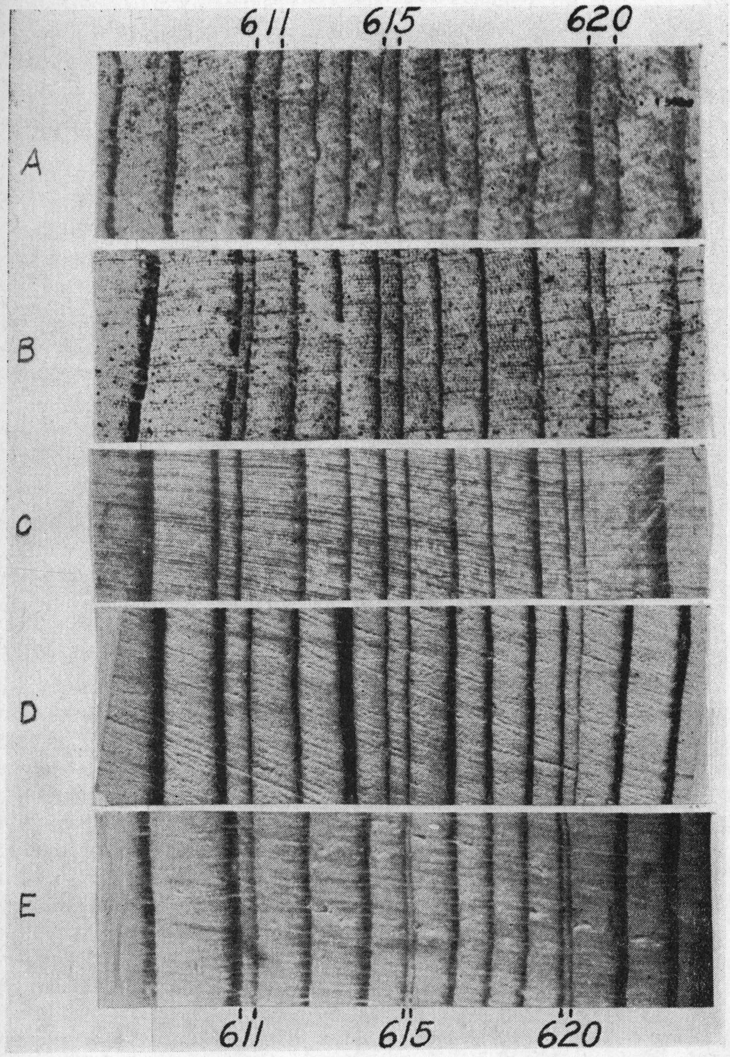


Plate VII.—Study in crossdating. Display of JCD signatures from different localities.

	Name	Location	Collected by	Size, 611 to 620 incl.
A	F-3992	Flagstaff, Baker Ruin	Mus. of N. Ariz.	4.6 mm.
B	MLK-35	Cave 2, Red Rock Valley	E. H. Morris	2.7 mm.
C	M-179	Mummy Cave, Cave 1	E. H. Morris	4.5 mm.
D	MLK-127	Broken Flute Cave, Red Rock V.	E. H. Morris	3.3 mm.
E	MLK-179	Broken Flute Cave, Red Rock V.	E. H. Morris	3.5 mm.

A and *B* are photo negatives of charcoal surfaces; *C* is diagonal cut on wood; *D* and *E* are transverse cuts on wood.

a case in charcoal, M-110, year A.D. 320 showing near a knot. A thickening of a latewood may sometimes appear to replace a missing ring. Under high power this may be resolved into a separate annual latewood in some local parts of the circuit.

In both missing rings and doubles the final decision usually comes easily in crossdating with other trees. Identification with the other ring records should be made in both earlier and later rings in order to reach it from both directions, and if there are enough specimens of good quality, the decision is easily found (Pl. VI).

Verified prediction.—In early chronologies such as in the third century and before, the number of specimens is too few to get much crossdating. Then the strongest evidence may come in finding missing rings in the predicted place by more complete search. This is one real purpose in taking great care to save every bit of an original charcoal specimen, which makes it preferable not to cut them into conventionalized forms.[10]

THIRD ESSENTIAL: CROSSDATING, THE MOST VITAL PART OF PRECISION DATING

Crossdating is the identifying of the same definite ring pattern in two or more trees, five at least being preferable, so that a dated ring in one tree gives the same date to that ring in the other trees (Pl. VII).

This third essential in precision dating is specially important because it is the key to all dendrochronology. Crossdating means individualizing the rings so that many rings of the same date may be found and the various appearances compared. That helps in correcting mistakes. The need for opportunity to do this in all dating attempts was what prompted the production of our MFA (Microfilm A) which presents nearly a thousand photographs of some hundreds of our best chronology specimens.[11] Thus in that film record the majority of rings individually appear in a half dozen to three dozen or more different trees from widely separated localities.

The present case is more important than that, for this similarity in chronological placement of individual rings is the basic evidence of the climatic origin of the differences between successive individual rings, for in each case a climatic element is the common and continuous

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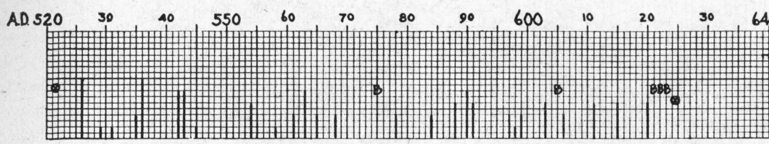
[10] An example of this verified prediction is given in the *Tree-Ring Bulletin,* Vol. 9, No. 2, October, 1942, p. 5, quoted in part as follows: "Since number FST-199, a fine series, showed 257-8 as exceedingly small, the assumption of their absence in number 200 would bring an almost perfect sequence in that specimen." The preceding words were written during the first examination of numbers 200 and 201. Two weeks later, a new surface was cut on an untouched part of FST-200, and there were the rings 257-58, as anticipated. That is what we mean by a "verified prediction" ring or a "forecast" ring (so called by Schulman).

[11] "Southwestern Photographic Ring Sequences," 1939, by A. E. Douglass. Bibliofilm Service, care Library, Dept. of Agriculture, Wash. D.C.

Skeleton Count, MLK 127

Lines under the date emphasize narrowness of ring.

A.D.	A.D.	A.D.
526	563	603
529	565	(605 B)
531	568	606
535-6	(575 B)	611
542-3	578	615
545	584	620
554	588	(621-2-3 B)
558	590-1	(624 Last)
561	597-8-9	



Skeleton Plot, MLK 127. Height of line shows narrowness of ring.

Figure 1.—*Above*, skeleton count; *below*, skeleton plot. (*Carn. Inst. Wash.* Publ. 289, Vol. III, 1936, p. 24.)

controlling factor in the ring's growth.[12] Of course this is only true in those trees growing in special sites where (in the Southwest) they get little or no water except the precipitation that falls very near them and whose sites do not have much power of conserving water supply. With conservation, small rings may become very complacent.

Crossdating is the "bridge" by which we carry dates from the interior ring patterns of a very old living tree to the outer ring patterns of a prehistoric tree and each extends the other's chronology. Thus our long ring-record chronologies are built back to A.D. 176.

Origin of crossdating.—There were certain accidental elements involved in our early attempts at chronology building in Arizona. The first group of specimens in 1906 had nineteen sections, averaging 350 years in age. They had grown about 12 miles southwest of Flagstaff in a shallow soil on hard malpais rock with enough slope to lose surface water quickly. These conditions were moderately favorable. The surfaces we produced on the transverse cross-sections were very poor, indeed. Some 6,000 or 7,000 rings were measured. Our next attempt in 1911 had better fortune. Some sixty-seven short sequences of fifty or sixty years each came from the granite soil areas just south of Prescott, Arizona. The granite soil holds water nicely for the trees to use in good years; but in dry years this water dries out readily, and local

[12] *Carnegie Year Book*, No. 31, 1932, p. 217.

trees are left to close their ring-building activity early in the season with very small rings and sometimes with none at all in parts of the trees. Thus the ring records become what we call sensitive. Another accidental feature helped us. These short sequences came to us as V-cuts from the outer edges of the stumps. The sides of the V-cuts had a direction at a less angle to the grain and so showed the rings with more precision. We understand that now but did not then.

But the chief features which led at once to important results were these: sixty-seven short sequences of fifty to sixty well-seen rings are more liable to catch the memory than nineteen sequences of 350 rings each. All this led to an unexpected result. After measuring eighteen specimens, it occurred to us that we were measuring the same ring sequences or pattern in each specimen, and each specimen came from a different tree. This was important and had to be tested; so a specimen that showed the rings well was taken as a standard and the other sixty-six ring records were compared with it. The pattern persisted through the entire group. This was indeed something new; it meant individualizing the rings; each ring could receive its own name which would be the date and the specimen in which it grew.

Slow recognition of precision.—During that period of developing recognition, crossdating was hampered by a long and ever-present puzzle of differences in different trees (mostly prehistoric specimens) in their capacity to show crossdating. We could not feel a complete sense of certainty in our dating until our obvious ring-type differences were understood. So at first in recognition of the presence of this unevaluated variable, we built up our lists of dates with a "certainty" index after each one, giving our estimate of confidence in the date assigned, on a scale of 10.

Our knowledge that local site was important came rather slowly in the sequoia work in 1915 to 1927 but the higher sensitivity in Arizona might be something else. In 1927 our attention went again strongly to prehistoric specimens, and in the next four years we visited some hundreds of the ruined villages near which these specimens had been living trees. This included the Flagstaff area and many sites on the Rio Grande and very many points between; it included the San Juan area, Aztec, Mesa Verde, and Durango on the north, to Hawikuh, Showlow, and Kinikinic on the south. This resulted in the first "principle" of dendrochronology already quoted,[13] that recognized the importance of the site of the individual tree.

This matter of site then explained the chief unrecognized factor that produced variations in crossdating quality. So at that time the long used estimate of "certainty" was dropped by considering certainties 9 and 10 on a scale of 10 as certain, those estimated at 8 were re-examined, and those at 7 or below were dropped from the lists of possibly dated specimens.

[13] *Ibid.*, p. 217.

The situation created by crossdating has had large extensions since then and in 1940 was expressed as follows:

> This identification of patterns over large areas changed fundamentally the method of getting information from tree rings, by introducing as the unit of information, not the individual tree, but a group of trees whose ring patterns crossdate. The resulting careful comparison between different trees not only locates and corrects the errors of the individuals as to false or missing rings, but also, because these continuous and common patterns are climatic, it insures the climatic origin of the factors on which the crossdating depends. Hence in chronology building we gather together units of this multiple, self-correcting type.[14]

Methods in crossdating.[15]—Crossdating is the comparison together of like ring patterns in different trees and the selection of the exact place at which correspondence between them is found. The method commonly used by the writer in wholly new material is to make for each specimen a skeleton count in a column, giving the number of each deficient ring in counting from the center or other starting point, and showing by underlines the relative intensity of its deficiency. Increased conservation year to year in the larger rings in the Southwest makes large rings much less available for this purpose. This count of small rings then is turned into a skeleton plot, giving on a time scale, usually 2 mm. to the year, these deficient rings expressed in vertical lines from the base of a long paper strip, the length of line being greater for more deficiency and specially long or dotted for absences. These can easily be compared together for the satisfactory relative place of each specimen and a composite made that can be compared with a master chart if one has been made. These records are preserved to constitute a file of the peculiarities of each specimen.

One must not forget that the skeleton plot which can be made in a few minutes in the field is not final and each specimen needs to be compared with the other specimens. Small V-cuts are convenient for this as they can be brought close together with corresponding rings actually touching; then as successive rings are brought into contact the eye follows along to see how the rings compare in their relative thickness. This has been called the "method of sliding coincidence." It is very hard to test charcoal pieces this way and so the common way is the "memory" method. After reviewing a half-dozen specimens of like pattern, the memory finds itself started on a small pattern common to the group; some distinctive feature makes an excellent beginning. With each specimen seen several times, the memorized pattern grows larger. These rings may receive any numbering always increasing toward the bark, i.e., in the direction in which the tree grows. Finally the location of this pattern in a master chart is usually easily secured by skeleton-plot guidance. Then the specimens are compared one by

[14] *Tree-Ring Bulletin*, Vol. 6, No. 4, April, 1940. "Editorial," p. 26.
[15] See Pl. VII.

one with the originals used in the master chart. As stated before a ready memory for numbers (dates, real or "floating") combined with ring picturizing is a great help. Thus the memory if sufficiently trained and frequently checked can be used in these comparisons.

TREE-RING CHRONOLOGIES

With these ideals we have constructed our chronologies in the Southwest back to A.D. 250 with, we believe, certainty in dating; and except for a remote possibility of change in the 240's this certainty extends to A.D. 176. Thence it is probably certain to about 100 and from there a complacent count goes to A.D. 11.

Our chronologies show strong variations in numbers of contemporary trees from century to century. The 100's and 200's have very few, of course. The 300's increase and the 400's have two dozen or so. The numbers decrease near 500 but in the late 500's grow to eighty. They are still at a maximum in the first half of the 600's and then drop to twelve more or less in the 700's. The 800's, 900's, and 1000's gradually increase to fifty and beyond, and the 1100's are less. The 1200's decrease sharply in the second half on approaching and entering the great drought, 1276-99. There are some fifteen or sixteen in those drought years. After that the numbers continuously increase toward and almost to the present time.

These numbers of contemporary trees are evidence of the reliability of the dating and give a picture of the times near 1300, 700, and 500 when the lack of specimens compelled us to take literally years of time to connect with certainty our ancient tree-ring records to modern dating. The full knowledge of that extreme care leads us to have more and more confidence in its trustworthiness. In the details back to A.D. 176 one feels sure that the main features of rainfall maxima and minima in the Pueblo area are fairly well represented in our plots and that the cyclic changes in them, which we find with our special cycloscope method of observing unstable periodicities, form the beginning of a real record.

GEOGRAPHICAL LOCATIONS

We were fortunate, indeed, in having a large climatically homogeneous area for these investigations and the building of a uniform and consistent chronology. In the Rio Grande Valley, charcoal specimens from prehistoric ruins were found to give some uncertain dates when judged in terms of our more western records. So we felt special satisfaction when the Laboratory of Anthropology in Santa Fe secured Mr. W. S. Stallings, who has had a long and close association with our tree-ring research to carry on dendrochronological work in the Rio Grande Valley. And his work has been very successful and will perhaps soon be published.

The extension of this sort of chronology building to widely different lands is always full of problems. So we are fortunate in the association with another indefatigable student, Mr. James L. Giddings, Jr., who has devoted many months to tree-ring work in our laboratory. He has done very valuable work in Alaska where crossdating qualities in trees are due to temperature stresses instead of moisture deficiency.

BASIC PRECISION OF DENDROCHRONOLOGY

Crossdating, as found in that first experience of 1911, put exactness into the dating of tree rings. It has not changed in that respect because we now know something of the site classification of forest trees; we know far better how to produce good surfaces and how to study the cell size, shape, and color; we know the "sliding coincidence" method of crossdating, the "memory" method, and the guidance of real skeleton plots. With all this the feeling of precision in our chronology building has grown stronger and stronger. We now have a vast number of satisfying crossdating agreements resulting from it; we have hundreds of cases of verified prediction that have sustained us in the most difficult places.

Those chronologies are already used in archaeological research. Their long climatic data are uniquely valuable in water supply histories, river runoff, and so forth. Any proposed theory of climatic change, developed with the idea of improving long range climatic forecasting, must conform to the data assembled here. We believe that these ring-record data will be a gateway through which advances will be made in important climatic knowledge.

UNIVERSITY OF ARIZONA PUBLICATIONS ON DENDROCHRONOLOGY

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No. 1.—Tree Rings and Chronology. A. E. Douglass. U. of A. Bull., Vol. 8, No. 4, 1937.

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No. 1.—Dendrochronology in Northern Alaska. J. L. Giddings, Jr. U. of A. Bull., Vol. 12, No. 4; Univ. Publ., Vol. 4, 1941.

No. 2.—Tree-Ring Hydrology of the Colorado River Basin. Edmund Schulman. U. of A. Bull., Vol. 16, No. 4, 1945.

No. 3.—Precision of Ring Dating in Tree-Ring Chronologies. A. E. Douglass, U. of A. Bull., Vol. 17, No. 3, 1946.
